KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS VOL. 3, NO. 4, August 2009

Fairness-insured Aggressive Sub-channel Allocation and Efficient Power Allocation Algorithms to Optimize the Capacity of an IEEE 802.16e OFDMA/TDD Cellular System

SangJun Ko and KyungHi Chang
The Graduate School of Information Technology & Telecommunications, Inha University
253 Yonghyun-Dong, Nam-Gu, Incheon 402-751, Incheon, Korea
[e-mail: sj987608@empal.com, khchang@inha.ac.kr]
*Corresponding author: KyungHi Chang

Received May 17, 2009; revised June 10, 2009; accepted June 15, 2009;
published August 31, 2009

Abstract

This paper aims to find a suitable solution to joint allocation of sub-channel and transmit power for multiple users in an IEEE 802.16e OFDMA/TDD cellular system. We propose the FASA (Fairness insured Aggressive Sub-channel Allocation) algorithm, which is a dynamic channel allocation algorithm that considers all of the users' channel state information conditionally in order to maximize throughput while taking into account fairness. A dynamic power allocation algorithm, i.e., an improved CHC algorithm, is also proposed in combination with the FASA algorithm. It collects the extra downlink transmit power and re-allocates it to other potential users. Simulation results show that the joint allocation scheme with the improved CHC power allocation algorithm provides an additional increase of sector throughput while simultaneously enhancing fairness. Four frames of time delay for CQI feedback and scheduling are considered. Furthermore, by addressing the difference between uplink and downlink scheduling in an IEEE 802.16e OFDMA TDD system, we can employ the uplink channel information directly via channel sounding, resulting in more accurate uplink dynamic resource allocation.

Keywords: 802.16e, OFDMA/TDD, sub-channel allocation, transmit power allocation, channel sounding

---

This work was supported by the Korea Research Foundation Grant funded by the Korean government (MOEHRD, Basic Research Promotion Fund) (KRF-2007-331-D00296 (I00048)).

DOI: 10.3837/tiis.2009.04.004

1. Introduction

OFDMA is recognized as one of the most promising multiple access techniques in future wireless communication systems [1]. Recently, a number of algorithms have been developed for channel allocation in OFDMA systems. While most of these algorithms focus on a single-cell scenario [2][3][4], a few studies have dealt with multi-cell OFDMA systems [5], [6]. The resource allocation algorithms proposed in [5] and [6], however, are only for throughput maximization, i.e., they assign resources unfairly by allocating more resources to users with good channel conditions, while the algorithms proposed in [3], [4], and [7] mainly consider fairness when allocating resources. In this paper, we propose FASA, which is a dynamic sub-channel allocation algorithm. We also propose a dynamic transmit power allocation algorithm, which is an improved version of CHC, for OFDMA systems. The proposed approach schedules the traffic of each user taking into account fairness, while maximizing the total system throughput.

The remainder of this paper is organized as follows. In section 2, the proposed FASA algorithm, which is a sub-channel allocation algorithm for an OFDMA system, is introduced. In section 3, the transmit power allocation algorithm, i.e., an improved CHC algorithm, is proposed. In section 4, the difference between uplink and downlink scheduling is addressed, and the uplink channel information is employed directly via channel sounding in the uplink of an IEEE 802.16e OFDMA/TDD cellular system. In section 5, the performance of the proposed algorithms is validated for the given simulation parameters and environments. Finally, conclusions are presented in section 6.

2. Proposed Downlink Sub-channel Allocation : FASA (Fairness Insured Aggressive Sub-channel Allocation) Algorithm

The proposed FASA algorithm consists of the following two stages.

1. User selection taking into account fairness among users via the GPF (General Proportional Fair) metric [3], [7].
2. Sub-channel allocation taking into account all of the users' channel state information conditionally via the ASA (Aggressive Sub-channel Allocation) algorithm [8], [9].

The following basic assumptions for the proposed FASA algorithm have been employed.

1. To avoid intra-cell interference, each sub-channel is allocated only to a single user.
2. There may be multiple sub-channels that have the same level of maximum channel gain, due to the quantized level of feedback channel state information.
3. A feedback path is assumed to report each user`s CQI and the actual downlink received data rate to the base station.

The proposed FASA algorithm can be implemented via the following four steps:

In the first step, the base station determines a user to be scheduled considering fairness based on the GPF metric [3], [7].

$$\text{GPF Metric} = \frac{R_k(t)}{T_k(t)}, \tag{1}$$

$$T_k(t) = \left(1 - \frac{1}{T_c}\right) T_k(t-1) + \frac{1}{T_c} R_k(t-1), \tag{2}$$

where $R_k(t)$ is the instantaneous data rate of user k. $T_k(t-1)$ is the data rate served until time $(t-2)$ and $R_k(t-1)$ is the actual received data rate of user k at time $(t-1)$. Here, T_c denotes the response time of the low-pass filter, which is set to 1,000 frames in this paper taking into account mobility.

In the second step, the base station searches sub-channel $n*$, which allows the maximum data rate to the selected user k_{FASA}, among sub-channels that have not been allocated to other users.

$$n* = \underset{n=0:N-1}{\arg\max}(r_{k_{FASA},n}), \tag{3}$$

where $r_{k_{FASA},n}$ is the data rate of user k_{FASA} that is allowed in the n^{th} sub-channel. Here, $n*$ may denote multiple sub-channel indexes that allow the same maximum data rate to the user k_{FASA}.

In the third step, the base station evaluates the supportable data rates on sub-channel $n*$ for other users, and then calculates the sum of data rates R_{n*} of all of the users except user k_{FASA} on the sub-channel $n*$.

$$R_{n*} = \sum_{\substack{k=0 \\ k \neq k_{FASA}}}^{K-1} r_{k,n} = \sum_{\substack{k=0 \\ k \neq k_{FASA}}}^{K-1} \frac{q_{n*}(k)}{T}, \tag{4}$$

where $q_{n*}(k)$ is the number of bits in each data symbol that are allocated to the sub-channel $n*$ of the k^{th} user, and T is the OFDM symbol duration.

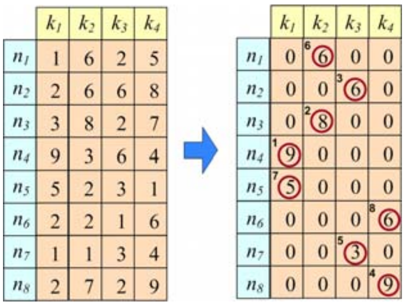
In the last step, the base station determines the sub-channel index to be allocated to the selected user taking into account the data rate R_{n*} as follows. If the sub-channel n^*_{opt} supports minimum data rates to other users (i.e., $n^*_{opt} = \arg\min(R_{n*})$), sub-channel n^*_{opt} is allocated to the selected user k_{FASA}.

Therefore, fairness is insured by the GPF algorithm and system throughput is simultaneously maximized by exploiting the channel state information of the selected user k_{FASA} and that of other users in the case of multiple instances of the same maximum level of channel state information. This procedure is applied to all of the users in the system. The 1-dimensional search procedure of the FASA algorithm to find the optimum sub-channel index for a selected user is much simpler than the 2-dimensional search procedure of the RCG (Rate Craving Greedy) algorithm [4]. In addition, loss of the system throughput induced by the FASA algorithm is negligible compared to the case of the RCG algorithm. The overall procedure of the proposed FASA algorithm is described in **Fig. 1**.

In **Fig. 2**, an example of the procedure for sub-channel allocation is illustrated for the case of the FASA algorithm. The example assumes that the total number of users is four, the total number of sub-channels is eight, and all of the users' required data rates are equal, where rows and columns indicate sub-channels and users, respectively. The data rate is given in the box for user k_j on the sub-channel n_i.

```
Initilization

    1. Set of available subchannels :
        $\mathrm{A} = \{0,\ 1,\ \dots,\ N-1\}$

    2. For every user, the available set of subchannels
       are empty :
        $\mathrm{A}_k = \{\},\ \ for\ k = 0,\ \dots,\ K-1$

    3. Data rate of $k^{th}$ user's at $n^{th}$ sub-channel :
        $r_{k,n}$

Algorithm

    Set user priority ($k = 0 : K$ -1)

        $T_k(t) = \left(1 - \frac{1}{T_c}\right) T_k(t-1) + \frac{1}{T_c} R_k(t-1)$

        GPF metric$_k = \frac{R_k(t)}{T_k(t)}$

    end

    $k_{FASA} = \arg\max_k \text{GPF metric}_k$
    $n^* = \arg\max r_{k_{FASA},n}$ ($n = 0 : N$ -1)

    If $k_{FASA}$ has multiple $n^*$,
        $n^*_{opt} = \arg\min\left( \sum_{k=0,\ k \neq k_{FASA}}^{K-1} \frac{q_{n^*}(k)}{T} \right)$
    else
        $n^*_{opt} = n^*$
    end

    Update Results
        $\mathrm{A}_{k_{FASA}} = \mathrm{A}_{k_{FASA}} \cup \{n^*_{opt}\}$
        $R_{k_{FASA}}(t) = r_{k_{FASA},n^*_{opt}}$
        $\mathrm{A} \quad = \mathrm{A} - \{n^*_{opt}\}$
```

Fig. 1. Procedure of the proposed FASA algorithm



	k_1	k_2	k_3	k_4
n_1	1	6	2	5
n_2	2	6	6	8
n_3	3	8	2	7
n_4	9	3	6	4
n_5	5	2	3	1
n_6	2	2	1	6
n_7	1	1	3	4
n_8	2	7	2	9

	k_1	k_2	k_3	k_4
n_1	0	^{6}⑥	0	0
n_2	0	0	^{3}⑥	0
n_3	0	^{2}⑧	0	0
n_4	^{1}⑨	0	0	0
n_5	^{7}⑤	0	0	0
n_6	0	0	0	^{8}⑥
n_7	0	0	^{5}③	0
n_8	0	0	0	^{4}⑨

Fig. 2. Illustration of the FASA algorithm

In the first step, the base station determines a user to be scheduled considering fairness based on the GPF metric. Such a user is selected as $k_{FASA} = k_1$ for scheduling. After the first step, the base station searches for a sub-channel that provides the maximum data rate to the selected user k_{FASA} among sub-channels that have not been allocated. In **Fig. 2**, sub-channel n_4 provides the maximum data rate for k_1, and thus n_4 is allocated to user k_1, n_3 is allocated to k_2, n_2 is allocated to k_3, and n_8 is allocated to k_4, consecutively. The base station then gives the highest scheduling priority to user k_3, because this user's GPF metric becomes maximal. In this case, both n_5 and n_7 support the same data rate of three.

$$r_{k_3,n_5} = r_{k_3,n_7} = 3. \tag{5}$$

However, the base station selects n_7 for user k_3 based on (6).

$$R_{n_5} = \sum_{\substack{k=1 \\ k \neq k_3}}^{4} \frac{q_{n_5}(k)}{T} = 8,$$
$$R_{n_7} = \sum_{\substack{k=1 \\ k \neq k_3}}^{4} \frac{q_{n_7}(k)}{T} = 6, \tag{6}$$

where R_{n5} and R_{n7} are the sum of the data rates of all of the users except user k_3 on sub-channels n_5 and n_7, respectively. That is, the sub-channel that gives the minimum contribution to the data rate of other users is selected by the base station. In the case of the conventional sub-channel allocation algorithm [4], n_5 is allocated to k_3, because scheduling in this case is processed according to the order of sub-channel number.

3. Proposed Downlink Transmit Power Allocation : Improved CHC Algorithm

In this section, an improved CHC algorithm is proposed for transmit power allocation in the downlink. The algorithm of [10] is an improvement over its predecessor where it allows sophisticated power allocation.

After sub-channel allocation, the base station initiates the transmit power allocation by allocating equal transmit power to all of the sub-channels using the EBP (Equal Band Power) algorithm [11], and calculates the CINR of each user in order to determine the corresponding MCS (Modulation and Coding Scheme) level. The improved CHC algorithm is then executed. It consists of the following three steps.

In the first step, the base station classifies all of the users into the following three groups.

1. The first user group (k_{Group1}) : Users who satisfy the minimum required data rate $R_{req,\min}$ according to the current MCS level.

$$R_{k_{Group1}} \geq R_{req,\min}. \tag{7}$$

2. The second user group (k_{Group2}) : Users who do not satisfy the minimum required data rate $R_{req,\min}$ according to the current MCS level.

$$R_{k_{Group2}} < R_{req,\min}. \tag{8}$$

3. The third user group (k_{Group3}): Users who have a smaller CINR value than that of the lowest MCS level MCS_0.

$$CINR_{k_{Group3}} < CINR_{MCS\_0}. \tag{9}$$

In the second step, the base station collects extra power that is above the level of the transmit power in order to maintain the users' current MCS level. It is collected from the users of the first and the second group. For example, if the received CINR of user *k*, $CINR_k$, is larger than the target CINR of the $(m-1)^{th}$ MCS level and smaller than that of the m^{th} MCS level, the MCS level of user *k* becomes $(m-1)$.

$$CINR_{MCS_{m-1}} < CINR_k < CINR_{MCS_m}. \tag{10}$$

Therefore, the base station collects extra power $Power_{Extra}$ of user *k* that is above the level of the transmit power in order to maintain the target CINR of the $(m-1)^{th}$ MCS level, as in (11).

$$Power_{Extra} = (Power_k - Power_{MCS_{m-1}}), \tag{11}$$

where $Power_k$ is the power allocated to user *k*, and $Power_{MCS_{m-1}}$ is the minimum required power to satisfy the $(m-1)^{th}$ MCS level.

```
First Step [User Grouping]
  First User Group    : $R_{k_{Group1}} \geq R_{req,\min}$
  Second User Group  : $R_{k_{Group1}} < R_{req,\min}$
  Third User Group    : $CINR_{k_{Group3}} < CINR_{MCS\_0}$

Second Step [Extra Power Collection]
  if $(CINR_{MCS_{m-1}} < CINR_k < CINR_{MCS_m})$
      $Power_{Extra} = (Power_k - Power_{MCS_{m-1}})$

Third Step [Extra Power Re-allocation]
  while $(Power_{Extra} > 0)$
    $k^* = \arg\max_{k \in Group2}(\ MCS_k\ )$
    $Power^* \ = \ Power_{MCS_{k^*}+1} - Power_{MCS_{k^*}}$

    if $(\ Power_{Extra} \ \geq \ Power^* \ )$
        $Power_{k^*} = Power_{k^*} + Power^*$
        $Power_{Extra} = Power_{Extra} - \ Power^*$
    else $(\ Power_{Extra} < Power^* \ )$
        $Power_{k^*} = Power_{k^*} + Power_{Extra}$
        $Power_{Extra} = 0$

    if $(R_{k^*} \geq R_{req,\ \min})$
        $Group\ 2 = Group\ 2 - k^*$
        $Group\ 1 = Group\ 1 \cup k^*$
  end while
```

Fig. 3. Procedure of the proposed improved CHC algorithm

In the third step, the base station reallocates the collected extra power to the users in the second group. To maximize the system throughput, the base station preferentially allocates the extra power to the second group user k who has the highest MCS level.

$$k^* = \arg\max_{k \in Group2}(\ MCS_k\ ), \tag{12}$$

where MCS_k is the MCS level of user *k* in the second group. The base station then calculates the required power $Power^*$ to boost to the next higher MCS level, and allocates the power to the selected user k^*.

$$\begin{aligned} Power^* &= Power_{MCS_{k^*}+1} - Power_{MCS_{k^*}}, \\ Power_{k^*} &= Power_{k^*} + Power^*. \end{aligned} \tag{13}$$

The overall procedure of the proposed improved CHC algorithm is illustrated in **Fig. 3**.

Based on the discussion presented in sections 2 and 3, throughput is maximized taking into account fairness, and power efficiency is simultaneously improved in the downlink of an IEEE 802.16e OFDMA/TDD cellular system.

4. Uplink Sub-channel Allocation via Channel Sounding

Channel sounding in the uplink enables the BS to measure uplink channel response and utilize resources effectively [12]. Resource management in an IEEE 802.16e OFDMA/TDD cellular system should consider the following differences between the uplink and downlink.

1) There is no reference symbol to measure the channel condition in the uplink, which is the preamble in the downlink.

2) Symbols in the downlink suffer interference from neighbor base stations but also suffer interference from neighboring users in the uplink, resulting in variation of the channel condition between the downlink and uplink, as shown in **Fig. 4**.

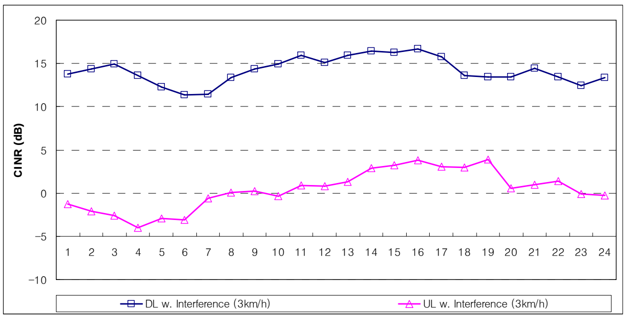


Fig. 4. Difference in channel condition between the downlink and uplink

That is, we cannot utilize CQI (Channel Quality Indicator) information for uplink scheduling; instead we obtain the uplink channel information via uplink channel sounding [12]. This allows more accurate uplink dynamic resource allocation. **Fig. 5** shows the frame structure, which contains a symbol for channel sounding in the uplink of an IEEE 802.16e OFDMA/TDD cellular system.

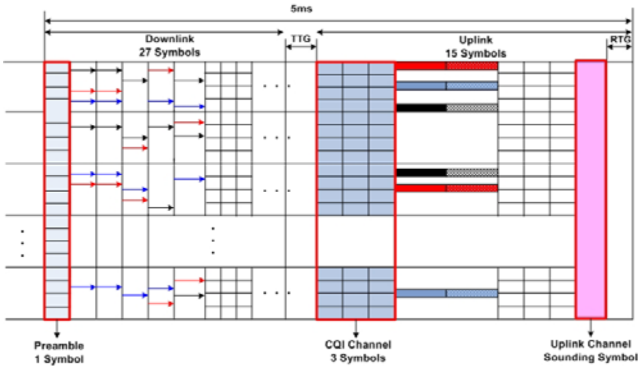


Fig. 5. The frame structure supporting uplink dynamic resource allocation via channel sounding

5. Performance Validation

In this section, performance improvements by the proposed dynamic sub-channel and transmit power allocation algorithms are demonstrated via simulations using the parameters given in **Table 1**, **2**, and **3**.

The fundamental OFDM link level simulation parameters are shown in **Table 1** [12]. There are 24 sub-channels in the total frequency-domain resource structure. A sub-channel consists of four bins, and a bin consists of nine sub-carriers. Among the sub-carriers, one pilot sub-carrier serves as a reference for channel estimation.

Table 1. OFDM link level parameters

OFDM Parameter	Value
Carrier Frequency	2.3 GHz
Effective Bandwidth	8.75 MHz
Sampling Frequency	10 MHz
Sampling Period	100 nsec
FFT & Used Sub-carrier	1024 / 864
Data & Pilot Sub-carrier	768 / 96
Sub-carrier Spacing	9.765625 kHz
Effective Symbol Duration	102.4 us
OFDM Symbol Duration	115.2 us
Frame Duration	5 ms
Symbols / Frame	42
Nr. of Symbols (DL : UL)	27 : 15
Sub-channels / Symbol	24
Sub-carriers / Sub-band	36

Table 2 shows that the required CINR values to guarantee a PER (Packet Error Ratio) of 1% for each MCS level are obtained via a link level simulation employing the parameters listed in **Table 1**. The fundamental OFDM system level simulation parameters are given in **Table 3** [13][14][15]. Besides, four frames of time delay for CQI feedback and scheduling are considered in this paper.

Table 2. MCS table to guarantee a PER of 1%

Link	Modulation Order	Coding Rate	Target CINR
DL	QPSK	1/12	- 5.17
		1/8	- 3.17
		1/4	- 0.17
		1/2	2.83
		2/3	4.39
	16 QAM	1/2	7.43
		2/3	9.89
	64 QAM	1/2	12.82
		2/3	15.29
UL	QPSK	1/2	2.83
		2/3	4.39
	16 QAM	1/2	7.43
	64 QAM	1/2	12.82

Table 3. System level simulation parameters

Item	Sub-Item	Parameter	Value
Link Modeling	BS	Tx power	43.0 dBm
		Max EIRP	55 dBm
		Antenna Gain	15 dBi
		Antenna Height	30 m
		Cable Loss	3 dB
		Thermal Noise	-174.0 dBm/Hz
		Noise Figure	3 dB
	MS	Tx Power	23.0 dBm
		Antenna Gain	0.0 dBi
		Antenna Height	1.5 m
		Thermal Noise	-174.0 dBm/Hz
		Noise Figure	5.0 dB
	Channel Model	Path Loss	ITU-R M.1225 Veh.
		Log-normal Shadowing	Std. Dev. 10 dB
		Fading Channel	ITU-R M.1225 Ped-A 3 km/h
Nr. of Cells			19
Cell Configuration			Hexagonal
Cell Radius			1 km
Nr. of Users / Sector			12
UE Position			Uniform
Resource Loading			100 %

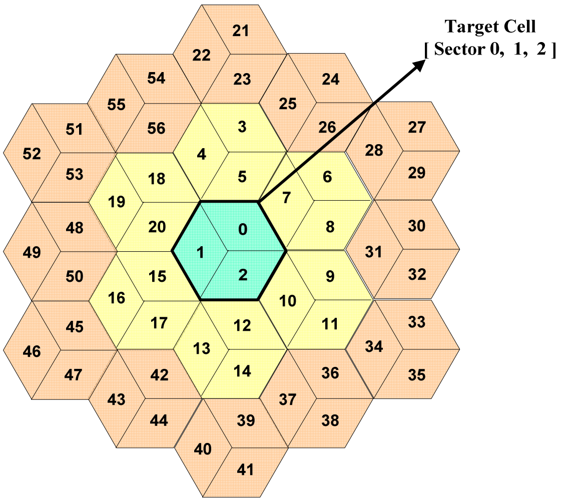


Fig. 6. 2-tier hexagonal cellular configuration

Fig. 6 depicts a 2-tier hexagonal multi-cell configuration. Each hexagonal cell consists of three sectors and the hexagonal cell in the center serves as a target cell to evaluate the performance of the proposed sub-channel allocation algorithm with the proposed transmit power allocation algorithm. Active users are generated in all of the 19 cells. We assume a frequency reuse factor of one; that is, each sector shares the total frequency-domain resources [16][17].

Fig. 7 shows the average downlink sector throughput employing four scheduling algorithms of sub-channel allocation only. That is, the proposed transmit power allocation algorithm has not been applied. The simulation results show that the proposed FASA algorithm yields 82 %, 193 %, and 4.9 % more sector throughput than the conventional Round Robin, RCG, and GPF algorithms, respectively. This gain is due to extensive use of the multi-user diversity gain considering all of the users' channel state information conditionally. In particular, we observe that the throughput of the RCG algorithm is quite small. This is due to the fact that we did not assume the system has infinite bandwidth to satisfy all of the users` data rates as in the original RCG algorithm.

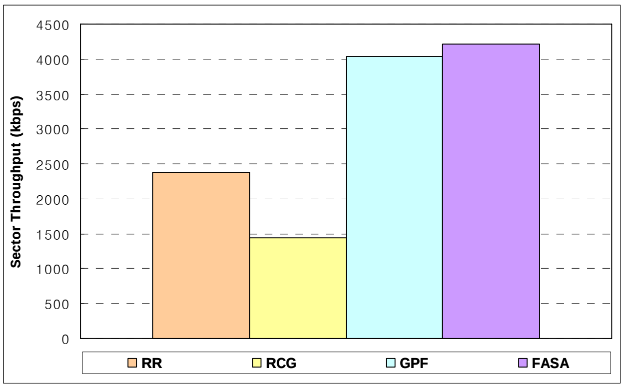


Fig. 7. Average downlink sector throughput employing four scheduling algorithms of sub-channel allocation only

Fig. 8 shows the downlink throughputs per user, employing the above four scheduling algorithms of sub-channel allocation only, which are summarized in **Table 4**. Taking into account fairness among users, the proposed FASA algorithm distributes the sub-channel more fairly to the users than the GPF algorithm. We define the FM (Fairness Measure) as follows.

$$\mathrm{FM} = \sqrt{\frac{\sum_{k=1}^{K}(R_{k,Req} - R_{k,Acq})^2}{K}}, \tag{14}$$

where k is the user index, and $R_{k,Req}$ and $R_{k,Acq}$ are the minimum required data rate and acquired data rate of each user, respectively.

Table 4. Average throughput per user and fairness measure

Algorithm	Average Throughput / User (kbps)	FM
Round-robin	198.8	89.5
RCG	119.7	46.2
GPF	336.1	118.2
FASA	342.3	117.9

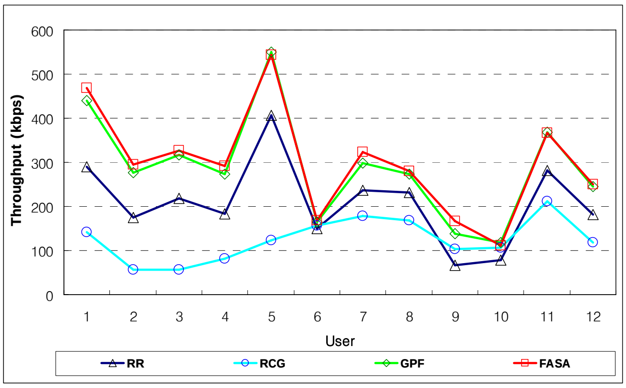


Fig. 8. Downlink throughput per user, employing four scheduling algorithms of sub-channel allocation only

The FM value of the proposed FASA algorithm is worse than that of the conventional round-robin and RCG algorithms, respectively. However, the fairness of the FASA algorithm can be improved by combining it with the proposed power allocation algorithm. Notably, the fairness of the RCG algorithm is outstanding, but the throughput per user is smaller than that of the proposed FASA algorithm.

By applying the joint allocation of the sub-channel and power, as proposed in this paper, the sector throughput and user throughput are obtained, as presented in **Fig. 9** and **10**. As a result of joint allocation with the improved CHC algorithm in **Fig. 9**, the sector throughput is increased by more than 25% compared to the case of sub-channel allocation only. In **Fig. 10**, users obtain more throughput than the threshold (256 kbps) via application of the joint allocation algorithm. The throughput per user and the fairness measure of the proposed joint allocation algorithm are summarized in **Table 5**. The FM value of the FASA algorithm, which is jointly operated with the proposed improved CHC algorithm, is better than that in the case of sub-channel allocation only. The improvement arises from efficient use of extra downlink transmit power and spectral diversity gain.

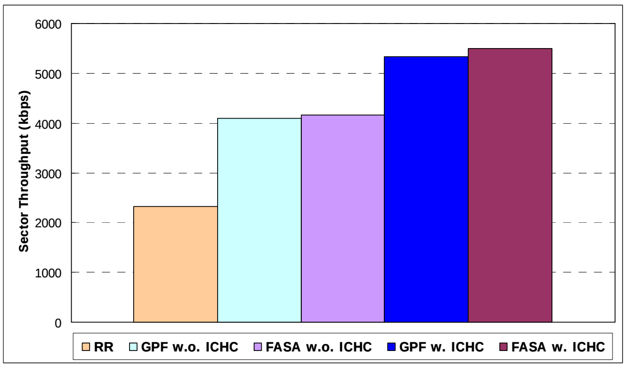


Fig. 9. Average downlink sector throughput via the proposed joint allocation algorithm

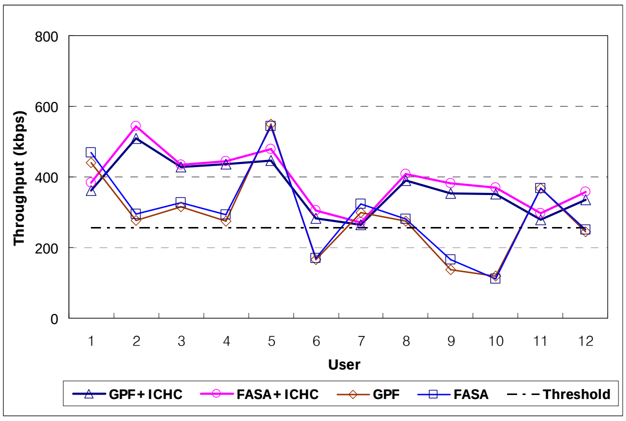


Fig. 10. Downlink throughput per user via the proposed joint allocation algorithm

Table 5. Throughput per user and fairness measure of the proposed joint allocation algorithm

Algorithm	Average Throughput / User (kbps)	FM
GPF w. ICHC	419.9	75.61
FASA w. ICHC	439.6	72.50
GPF	336.1	118.2
FASA	342.3	117.9

Fig. 11 shows the average uplink sector throughput in the case where channel sounding is employed. By applying CQI measured from the downlink, the sector throughput of the GPF and FASA algorithms increases by more than 16.3% and 22.7%, respectively, compared to the case of the round-robin. In the case of employing the uplink channel information directly via channel sounding, the GPF and FASA algorithm yields 25.4% and 31.8% improved sector throughput, respectively, relative to the round-robin. Thus, the efficiency of resource allocation in the uplink of IEEE 802.16e OFDMA/TDD is improved by adopting channel sounding information from the uplink.

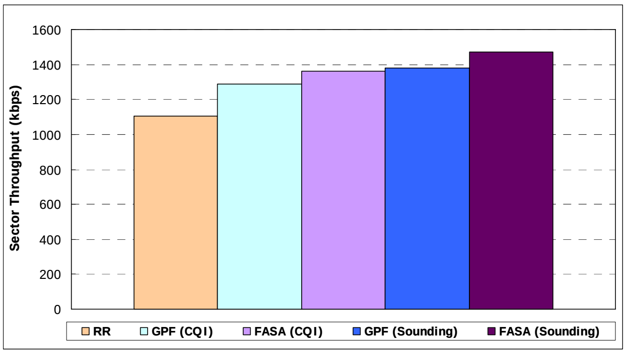


Fig. 11. Average uplink sector throughput employing channel sounding

6. Conclusions

This paper solves the problem of joint optimization of sub-channel and power allocation for multiple users in an IEEE 802.16e OFDMA/TDD cellular system, taking into account the practical latency for CQI feedback and scheduling. FASA, a sub-channel allocation algorithm, maximizes the system throughput by exploiting the channel state information of the selected user and that of other users in the case of multiple instances of the same maximum level of channel state information. The benefit of FASA, compared to RR, RCG, and GPF, stems from extensive use of the multi-user diversity gain considering all of the users' channel state information conditionally. Joint allocation with an improved CHC power allocation algorithm provides an additional increase of sector throughput while simultaneously enhancing fairness. The improvement originates from the efficient use of extra downlink transmit power and spectral diversity gain. By addressing the difference between the uplink and downlink scheduling in an IEEE 802.16e OFDMA TDD system, we can employ the uplink channel information directly via channel sounding, resulting in more accurate uplink dynamic resource allocation.

References

[1] C.Y. Wong, R.S. Cheng, K.B. Letaief,, and R.D. Murch, "Multiuser OFDM with adaptive subcarrier, bit, and power allocation," *IEEE J. Selected Areas in Commun.*, pp. 1747-1758, Oct. 1999.

[2] G. Song and Y. Li, "Adaptive resource allocation based on utility optimization in OFDM," *in Proc. IEEE Globecom.*, San Francisco, Dec. 2003, pp. 586-590.

[3] Wengerter. C., Ohlhorst. J., Elbwart. A.G.E., "Fairness and throughput analysis for generalized proportional fair frequency scheduling in OFDMA," *in Proc. IEEE VTC-Spring*, May. 2005, pp. 1903-1907.

[4] Kivanc, D., G. Li, and H. Liu, "Computationally efficient bandwidth allocation and power control for OFDMA," *IEEE Transaction on Wireless Commun.*, pp. 1150-1158, Nov. 2003.

[5] J. Li, H. Kim, Y. Lee and Y. Kim, "A novel broadband wireless OFDMA scheme for downlink in cellular communications," *in Proc. IEEE WCNC*, New Orleans, Mar. 2003.

[6] G. Li and H. Liu, "Downlink dynamic resource allocation for multi-cell OFDMA system," *in Proc. IEEE VTC*, Orlando, Oct. 2003.

[7] Aniba G. and Aissa S, "Adaptive proportional fairness for packet scheduling in HSDPA," *in proc. IEEE GLOBECOM*, Nov. 2004, pp. 4033-4037.

[8] S.J. Ko, J. Heo, and K.H. Chang, "Aggressive sub-channel allocation algorithm for intelligent transmission in multi-user OFDMA system," *LNAI, Int. Conf. on KES*, Oct. 2006.

[9] S.J. Ko, J. Heo, and K.H. Chang, "Aggressive sub-channel allocation algorithm for efficient dynamic channel allocation in multi-user OFDMA system," *in Proc. PIMRC*, Mar. 2006.

[10] J. Heo, I.S. Cha, and K.H. Chang, "A novel transmit power allocation algorithm combined with dynamic channel allocation in reuse partitioning-based OFDMA/FDD system," *in Proc. IEEE ICC*, June 2006, WC52-4.

[11] J.H. Jang and K.B. Lee, "Transmit power adaptation for multiuser OFDM systems," *IEEE J. Selected Areas in Commun.*, pp. 171-178, Feb. 2003.

[12] IEEE P802.16e / D11-2005, IEEE Standards for local and metropolitan area networks part 16 : Air interface for fixed broadband wireless access systems.

[13] 3GPP R1-030042, Update of OFDM SI Simulation Methodology, Jan. 2003.

[14] Recommendation ITU-R M.1225, Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000, 1997.

[15] CDG Evolution Study Report, Revision 4.00, Dec. 1999.

[16] J. Heo, S.H. Park, and K.H. Chang, "An effective downlink resource allocation for supporting

heterogeneous traffic data in an OFDM/SDMA-based cellular system," *in Proc. GLOBECOM*, Nov. 2006.

[17] J. Heo and K.H. Chang, "Transmit and receive beamforming for OFDMA/TDD system," International Symposium on Antenna and Propagation, Aug. 2005, pp.27-30.

SangJun Ko received a BS degree in geographic information system engineering from Inha University, Incheon, Korea, in 2005. He received his MS degree in the Graduate School of Information Technology and Telecommunications at Inha University, Incheon, S. Korea, in 2007. Since 2007, he has been with LG Electronics, Korea, as a researcher. His research interests include 4G wireless communication systems, Cognitive Radio, WiBro, and Dynamic Resource Allocation.

KyungHi Chang (M’93–SM’98) received BS and MS degrees in electronics engineering from Yonsei University, Seoul, S. Korea, in 1985 and 1987, respectively. He received his PhD degree in electrical engineering from Texas A&M University, College Station, Texas, in 1992. From 1989 to 1990, he was with the Samsung Advanced Institute of Technology (SAIT) as a member of the research staff, and was involved in digital signal processing system design. From 1992 to 2003, he was with Electronics and Telecommunications Research Institute (ETRI) as a principal member of the technical staff. During this period, he led the design teams working on WCDMA UE modem and 4G radio transmission technology. He is currently with the Graduate School of Information Technology and Telecommunications, Inha University, where he has been a professor since 2003. His current research interests include RTT design for IMT-Advanced and 3GPP LTE systems, WMAN system design, cognitive radio, cross-layer design, cooperative relaying systems, and RFID/USN. Dr. Chang has served as a senior member of the IEEE since 1998. Currently, he is an editor-in-chief of the Korean Institute of Communication Sciences (KICS) Proceedings. He has also served as an editor of ITU-R TG8/1 IMT.MOD and is currently an international IT standardization expert of the Telecommunications Technology Association (TTA).